A UNITED STATES DEPARTMENT OF COMMERCE PUBLICATION

NBS TECHNICAL NOTE 757

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U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

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U.S. DEPARTMENT OF COMMERCE, Peter G. Peterson, *Secretary*

NATIONAL BUREAU OF STANDARDS, Lawrence M. Kushner, *Acting Director*,

Issued January 1973

National Bureau of Standards Technical Note 757
Nat. Bur. Stand. (U.S.), Tech. Note 757, 20 pages (Jan. 1973)
CODEN: NBTNAE

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
(Order by SD Catalog No. C13.46:757). Price 45 cents.

THE SMOKE DENSITY CHAMBER METHOD FOR EVALUATING THE POTENTIAL SMOKE GENERATION OF BUILDING MATERIALS

T. G. Lee

The paper reviews the Smoke Density Chamber Test Method and illustrates its use and application to assess smoke generation of building materials in fire situations. It shows how test results may aid the Fire Services and code authorities in evaluating and reducing the potential light-obscuration hazard of smoke in buildings. An example is given for calculating visibility in a simplified fire situation involving material of known smoke generation. The smoke generation of some common interior finish and construction materials are given.

Key words: Building Codes; building materials; fire; Fire Services; smoke; smoke density chamber; smoke generation; test method; visibility.

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1. Introduction

There is a well known adage, "where there's smoke, there's fire." Fire is one of the foremost causes of accidental injury and we suffer the consequences of its by-product, smoke.

Statistics show that "smoke inhalation" and "asphyxiation" rather than burn injury cause a majority of the fire fatalities in this country. It is not accurately known how many people are trapped by decreased visibility due to dense smoke and who eventually succumb to the direct effects of fire and smoke in the immediate vicinity of the fire. Smoke can also cause apprehension, panic, or even death to occupants in other parts of a building because of smoke movement induced by natural convection or by mechanical ventilating systems. Furthermore, property losses are greatly increased because smoke also impedes fire fighting efforts. A smoke logged building often requires venting, in order to clear out smoke and hot gases. This generally increases the fire severity, but allows the fire fighting to be accomplished more effectively. The extent of these difficulties depends on the amount and rate of smoke generation in a given fire.

The increased use of plastics in coatings insulations, furnishings, and other materials of construction has changed the type and volume of smoke

generated and thereby broadened the fire problem. Chemical treatments or retardants added to reduce flammability of material may also increase the smoke generated in a fire.

One way to reduce problems associated with smoke is to provide reliable and meaningful information on the smoke generation of common materials. Such data may then be used by building designers, owners, or code officials in selecting materials of construction and furnishings at various levels of risk. For example in certain locations where smoke is critical such as in shafts, heating plant rooms and enclosures, exitways, duct linings, and filters in air conditioning systems, material of low smoke potential may be selected.

We have come to understand the concept and the application of <u>fire load</u>[1] in the design of fire resistive walls, columns, and floors. We should now begin thinking in terms of a <u>smoke load</u>[2] so that a rational building design will allow control of smoke by automatic venting, dilution, and/or shaft (i.e. stair and elevator shaft) pressurization in high rise buildings.

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[1] Fire load: the total heat which could be liberated by the complete burnout of combustible materials in a prescribed area. Commonly expressed in terms of weight of combustibles per square foot of floor area in a compartment on the basis of a calorific value of 8000 Btu/lb.

[2] Smoke load: the total smoke which could be liberated by the combustion of furnishings and finish materials in a compartment under prescribed exposure conditions. It may be based on the summation of the product of specific optical densities and the area of smoke producing materials associated with a given volume. The specific optical densities are determined by measurements of sample specimens in the standardized Smoke Density Chamber.

At the present time very little meaningful data on quantitative smoke production are available to those who wish to design low-risk facilities such as nursing homes.

2. Requirements of a Meaningful Test Method

To date, smoke requirements have been used only sparingly; this is due partly to a lack of knowledge on how to apply smoke limitations, and partly to a lack of a meaningful test method. The need for a quantitative means for smoke measurement, based on flaming and nonflaming modes of exposure was clearly apparent to fire research workers, in both government and private organizations.

The Smoke Density Chamber meets all the following essential requirements of a good laboratory test method for measuring smoke generation of materials:

1. It must give relevant and useful results. Exposure conditions in the test should simulate important and typical parameters experienced in a real fire. For example, the amount and rate of smoke generation for most materials depends on whether the specimen is exposed to flame or just radiant heating.
2. The method must provide reliable and quantitative results. The degree of reproducibility (among laboratories) and repeatability (within a laboratory)

of the test results, determined by interlaboratory evaluations of the test method, must be acceptable.

3. The method must provide a continuous scale of measure and have sufficient resolution to cover the common materials. It should be capable of measuring the total smoke generated as well as the amount released over a specified time period.

4. The result must be understandable to various user groups (Fire Service, code official, architect, engineer, etc.) and fit the concept of performance criteria in building code enforcement. A building designer should be able to use the data to design for the possible smoke load. He should, for example, be able to select a material with moderate potential smoke generation to cover small parts of a room (or its furnishings), and a material of very low potential smoke in the rest of the room; so that the total smoke generation does not exceed some agreed upon limit.

3. The Test Method, Reliability, and Limitation

3.1 The Test Method

The test method, using the Smoke Density Chamber, was developed in 1966 by the Fire Research Section at the National Bureau of Standards (NBS) for the measurement of smoke potential of solid materials.[1] [1] Several

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[1] The original work was supported by the Federal Housing Administration as part of a technical study of test methods and performance criteria for wall systems.

TABLE 1

Smoke Generation of Selected Specimens

Specimens	Thickness inch	Density lb/ft^3	Density oz/yd^2	Smoke (D_m) Non-Flam.	Smoke (D_m) Flaming
<u>Wall & Ceiling Material</u>					
Asbestos Cement Board	0.187	125		0	0
Gypsum Board (unfinish, paper)	0.375	51		35	10
Plywood	0.17	32		305	45
Fiber Board	0.5	16		230	75
PVC Veneer on Gypsum	0.5	51		109	110
(Veneer)	(0.01)				
<u>Flooring</u>					
Red Oak Flooring	0.75	39		505	300
Vinyl Asbestos Tile	0.062	93		240	325
Polyamide (aromatic) carpet	0.22		49	175	105
Nylon (foam backing) carpet	0.39		86	310	270
Acrylic carpet	0.375		82	470	220
<u>Polymer Sheet</u>					
Polyvinyl Chloride	0.01	87			100
Polyvinyl Chloride	0.015	87			210
Polyvinyl Chloride	0.03	87		120	430
Acrylonitrile-Butadiene-Styrene	.022	66		188	
Acrylonitrile-Butadiene-Styrene	.032	66		220	450
Glass Reinforced Polyester	.110	48		420	720
<u>Wood</u>					
Elm	0.05	40		150	35
Elm	0.125	40		270	
Elm	0.185	40		390	65
Elm	0.24	40		510	
<u>Insulation</u>					
Glass Fiber Insulation	1.0	3.5		25	25
Polystyrene Foam (Rigid)	1.0	1.8		25	390

of the early applications of the Smoke Density Chamber were the measurement of smoke produced by aircraft interior finish materials [1] and the effect of ventilation on the smoke produced by wood and plastic materials [2]. References [3] and [4] give the complete theory, construction details and the test method procedures of the Smoke Density Chamber. The Chamber is an 18 ft^3 closed cabinet in which a specimen three inches square is supported vertically in a holder and is exposed to heat under one of two conditions, designated as "flaming" or "nonflaming" (smoldering). The thickness and mounting of the test specimens should match the end use (installation) thickness and mounting. For each specimen, the combustion generated smoke accumulates within the chamber and the reduction of light transmission during the test is reported in terms of optical density of the smoke. The principle of smoke measurement in the chamber is based on application of the law of light absorption through solid or liquid aerosols commonly referred to as the Beer-Lambert Law [3]. Optical density is the single measurement most characteristic of a "quantity of smoke." The data from the chamber gives both the maximum optical density and the rate of increase in optical density during the test. To simplify use of the test results, however, only the maximum optical density, D_m, may be used to estimate the potential smoke generation of materials in building fires. The range of the instrument is between 0 and 800 units which adequately covers the D_m levels for most building finish materials.

Table 1 shows the maximum specific optical density of some common materials under flaming and nonflaming exposure conditions. In general,

TABLE 2

Combined Results of Interlaboratory Evaluation of Smoke Density Chamber (AMINCO) Test

Specimen	Thickness in.	Mean D_m(corr.)	Reproducibility		Repeatability	
			Standard Deviation	Coefficient of Variation %	Standard Deviation	Coefficient of Variation %
Non-flaming Exposure						
Linoleum	0.125	725	49	6.7	46	6.4
Polypropylene Rug	0.22	621	52	8.4	28	4.5
Red Oak	0.25	552	40	7.2	18	3.2
ABS/.022	0.022	188	20	11	12	6.4
α-Cellulose	0.03	162	4.7	2.9	4.2	2.6
PVC-Gypsum	0.5	109	6.6	6.0	3.5	3.2
Polystyrene Foam	1.0	23	6.3	27	6.7	29
Flaming Exposure						
GRP	0.062	719	49	6.8	36	5.0
ABS/.032	0.032	451	17	3.8	20	4.5
Polystyrene Foam	1.0	391	52	13	32	8.0
Polypropylene Rug	0.22	292	24	8.3	20	6.9
PVC-Gypsum	0.5	109	29	27	12	11
Acoustic Tile	0.75	23	2.7	12	3.4	16

specimens from wood products gave higher smoke values under the non-flaming than under the flaming exposure condition while for solid plastic materials, the reverse was true.

Although not a part of the smoke density measurement and not discussed in this paper, the Smoke Density Chamber can also be used for the simultaneous measurement of the concentration of potentially toxic gases and vapors.

3.2 Reliability

The reproducibility of the test result from one laboratory to another compares favorably with other fire test methods. Several interested laboratories constructed their own chambers based on the published drawings and used the method to measure the smoke produced by a variety of materials [5,6]. This led, in 1970, to the production of a commercial version of the chamber incorporating a number of refinements by the American Instrument Company (AMINCO).

Twenty-two laboratories (18 with identical AMINCO chambers, four with "home-made" chambers) have participated in an inter-laboratory evaluation of the method involving eight common building materials under the pre-scribed flaming and nonflaming exposure conditions [4]. Several recommendations for procedural changes by the participants were accepted and are included in the latest test method standard; see Appendix II, NBS Technical Note 708 [4]. Table 2 shows a summary of these results

including supplemental flaming tests by twelve laboratories. The median reproducibility (among laboratories) for a variety of materials under the two exposure conditions was on the order of 8%.

Two standard reference materials to check the performance of the chamber are available from the Office of Standard Reference Materials, National Bureau of Standards.

3.3 Limitations

This test, in common with some other fire tests, does not measure an inherent property or "smoke characteristic" of a material; what the test does measure is the light obscuration characteristic of smoke generated by a particular material or assembly (of prescribed density, thickness, moisture content, etc.) under two stipulated conditions of fire exposure. At the present time, it is not possible to predict smoke production from a specimen without testing. For a solid uniform material, the smoke generated increases proportionally with thickness up to a certain thickness depending on its density and thermal properties. Specimens submitted for testing should be identical in all respects including thickness to that to be used in the field. The test specimen holder can handle specimens up to one inch thick.

4. How to Use the Data to Estimate Relative Smoke Hazard

In practical situations where no information is available on the disposition of interior finish material in the building, D_m may be used to

estimate the comparative light-obscuration hazard of smoke from burning different specimens. A simple specification, for example, could require that the surface finish materials of a room or other space not exceed a value of D_m based on the average of flaming and nonflaming exposure conditions, or alternately based on the higher value. However, to be accurate, information on the volume of the room or building, and the size, and type of the material should be used by designers to calculate the potential smoke load. Consideration should also be given to the effect of air dilution in the room or building as a basis of estimating possible smoke levels in the event of fire.

The maximum optical density D_m is a property of the particular specimen, its thickness and type of backing. If the identical material were to be similar exposed in a room, visibility, through the smoke generated in that room neglecting eye irritation, may be estimated from data based on the laboratory tests. To do this, we take into account the three geometrical factors affecting smoke density:

- the exposed <u>area</u> of material producing smoke, (A)
  - Greater area, more smoke;
- the <u>volume</u> of the room in which the smoke is accumulating (V)
  - Greater volume, lower density (concentration);
- the <u>length</u> of vision path (L)
  - Greater length, reduced visibility.

The estimated density of smoke (D/L) in a room can be calculated from the (D_m) value in the test chamber by the following equation:

$$D/L = D_m \times A/V \qquad \text{Equation (1)}$$

The relation between visual distance and smoke density is determined experimentally. Figure 1 is based on data from Jin [7] for smoke of various types. It represents the visual threshold response for several observers situated outside the room viewing through a window either a back-lighted sign or a side illuminated placard. These results show that for a given smoke density, the visual distance is affected primarily by the brightness of the sign and only slightly by the color of the smoke, burning conditions and type of material used. However, other studies have indicated variability in the relationship between visual distance and smoke density as summarized in the review by McGuire et al [8]. All of this work has ignored the irritant and lachrymatic effect that the smoke may have on an occupant located within the room.

The following example shows how data from the Smoke Density Chamber may be used to estimate the visibility in a hypothetical situation. It is desired to estimate the visibility in a 3200 ft^3 room where a 32 ft^2 area of material is exposed to fire over its entire surface and is the only material producing smoke. A test specimen of thickness identical to that of the panel is tested in the Smoke Density Chamber and the measured maximum specific optical density (D_m) is 100.

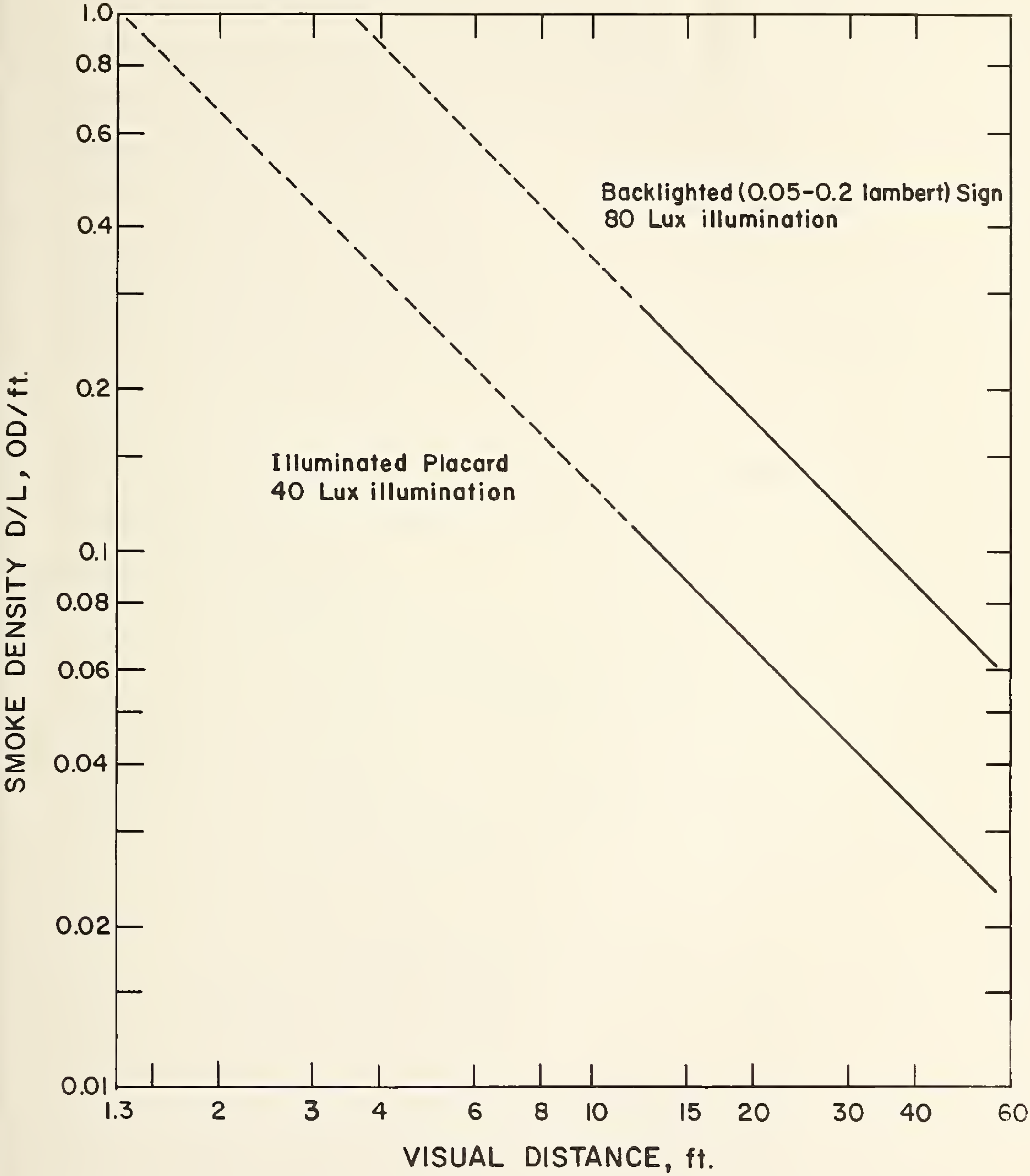

Fig. 1. Smoke Density and Visual Threshold of Signs Based on Data Ref. [7].

Substituting these numbers in equation (1), the smoke concentration (optical density per unit length) in the room will be:

$$D/L = 100 \times 32/3200 = 1.0 \text{ per foot}$$

Though experimental data on visibility in the 1.0 optical density per foot range was not given by Jin, extrapolation of the curves in Figure 1, (for illustration purposes) may be used to estimate visibility. D/L = 1.0 corresponds to a visual distance of only 3.5 ft for a back lighted (exit) sign under a typical light level of 80 lux* (without smoke) and 1.3 ft for a side illuminated placard under a light level of 40 lux.

However if the smoke were diluted from the room by natural convection due to stack effect or by a forced air ventilating system into the whole building with a volume of 45,000 ft^3, the smoke concentration assuming no losses will be:

$$D/L = 100 \times 32/45{,}000 = .071 \text{ per foot}$$

From Figure 1, D/L = .071 corresponds to a threshold visual distance of about 50 ft for the back lighted (exit) sign and about 18 ft for the side illuminated placard under the same lighting conditions.

5. How the Smoke Density Chamber Can Aid the Fire Services and Building Code Officials

The Fire Services in various jurisdictions have realized the critical nature of the problem of smoke in high density public occupancy buildings

* NFPA No. 101-1970 standard for exit sign calls for a minimum of 5 foot-candle or approximately 54 lux on the illuminated surface.

such as nursing homes, apartment buildings, and hotels. Some jurisdictions have enacted ordinances for its control. The Smoke Density Chamber is offered as a tool to evaluate the potential smoke generation which may occur in a room, a corridor, or a building caused by either surface finishes or by contents.

A test method based on the use of the Smoke Density Chamber has been submitted to ASTM for consideration and possible promulgation as a voluntary standard. At the present time over 70 chambers of the commercial type are being used by industrial, research and testing laboratories in this country and abroad. The following commercial testing laboratories have reported that they can provide the test service for the public:

American Instrument Company
Silver Spring, Maryland 20910

Underwriters' Laboratories, Inc.
Northbrook, Illinois 60062

Southwest Research Institute
San Antonio, Texas 78228

U. S. Testing Company
Hoboken, New Jersey 07030

6. Summary and Conclusion

The Smoke Density Chamber is a method for the measurement of the smoke generation of materials based on common fire exposure situations. A large number of industrial and government research laboratories have used the method to develop information on the smoke generation of a wide variety of materials. Tests are also being performed by several

commercial testing laboratories. Reduction of visibility by smoke without consideration of its irritant effect may be calculated based on the results of laboratory tests. The precision of the method has been determined by inter-laboratory evaluation using typical materials. Standard reference materials are available for the test calibration. The concept of the Smoke Density Chamber method is proposed as a suitable first step in evaluating the production of smoke and as a basis for future code requirements. Limitation on the use of materials on the basis of smoke production or smoke load in building may vary, however, depending on fire experience, type of occupancy, level of risk, and type of built-in protection used. These factors should be considered in any requirement to be established.

7. References

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☆ U. S. GOVERNMENT PRINTING OFFICE : 1973—511-322/146

FORM NBS-114A (1-71)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBS TN-757	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE The Smoke Density Chamber Method for Evaluating the Potential Smoke Generation of Building Materials			5. Publication Date January 1973 6. Performing Organization Code
7. AUTHOR(S) T. G. Lee			8. Performing Organization
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address Same as 9			13. Type of Report & Period Covered 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

The paper reviews the Smoke Density Chamber Test Method and illustrates its use and application to assess smoke generation of building materials in fire situations. It shows how test results may aid the Fire Services and code authorities in evaluating and reducing the potential light-obscuration hazard of smoke in buildings. An example is given for calculating visibility in a simplified fire situation involving material of known smoke generation. The smoke generation of some common interior finish and construction materials are given.

17. KEY WORDS (Alphabetical order, separated by semicolons) Building materials; fire; fire services; smoke; smoke density chamber; smoke potential; test method; visibility.

18. AVAILABILITY STATEMENT	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
☒ UNLIMITED.	UNCLASSIFIED	20
☐ FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NTIS.	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price 45 cents

USCOMM-DC 66244-P71